

Name _____ Date _____ Time to Complete ____h ____m
Partner _____ Course/Section ____/____ Grade _____

Complex Circuits

Introduction

In this laboratory you will continue your exploration of dc electric circuits with a steady current. The circuits will be more complicated than in the previous lab, involving multi-bulb circuits in series, parallel and series/parallel combinations.

The purpose of these exercises is to extend your understanding of the “physics” of simple electrical circuits. That is, the purpose is for you to learn qualitative properties of circuits. There is an additional purpose, to help you learn the skills of being able to predict what you expect to happen, observe what happens, and correct the original misunderstanding, if necessary. What you learn in assembling, observing, and measuring the properties of these circuits will be applicable to the real-world electrical circuits you will meet on the job and in everyday life.

Equipment

NOTE: The multimeter’s 10 AMP range, instead of the 300 mA range, should be used for all current measurements.

1. Series connections

a. A second type of bulb

Introduction

This week you will use two different types of bulbs. One is the 502 type used in the last lab. The other is different, a model 425, that you will find mounted on an orange base. Except for the model number, at first glance these bulbs look similar. Are they identical? (Rhetorical)

Procedure

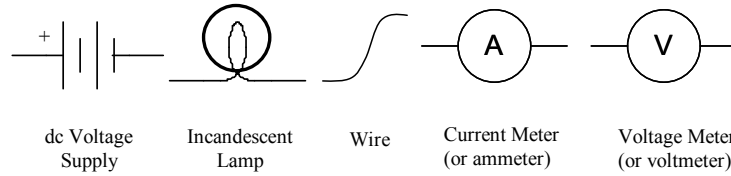
- Construct a single-bulb circuit with the power supply set at 5 volts using the 502.
- Now assemble the circuit using the 425 instead. Comment on their relative brightness.

Conclusion

Is a 425 bulb identical to a 502 bulb? If not, speculate on what physical difference in their structures might lead to their different behavior under identical operating conditions. By careful visual inspection can you confirm any of your speculations? Comment.

Procedure cont.

One way this structural difference will manifest itself, besides different brightness for the same supply voltage, is as a difference in filament resistance. Plan a procedure to determine the resistance of each bulb's filament while powered by the supply set at 5 V. Draw circuit diagrams in the box below that illustrate the measurements you plan to make. Use these symbols in your diagrams.



Carry out the measurements, clearly and neatly record your results, and show all work in any calculations performed to compute the resistances.

Conclusion

Recall from last week's lab that a light bulb's resistance depends on how hot it is, which depends on the current. In light of this fact it very important that you state clearly the specific operating conditions under which the bulbs' resistances are being compared. In this comparison, in which both bulbs are powered by the same 5V supply voltage, but filament temperatures are different (the *color* of the light is the best indicator of filament temperature), which bulb has the greatest resistance? Which bulb draws the most current from the supply? Are your answers consistent?

Describe two ways that one filament, made of the same material and at the same temperature as another, could be made to have a greater resistance.

b. Two different bulbs in series

Introduction

[Note: Make your prediction before you construct the next circuit.] When each type of bulb is powered individually by a 5V supply, you now know which type is brighter, which draws more current and which has a higher resistance. Next you will explore if this is enough information to predict how the two bulbs behave when they are both wired into the same circuit in an arrangement that is called a *series* combination. A circuit with two bulbs in series is shown in *Figure 1*.

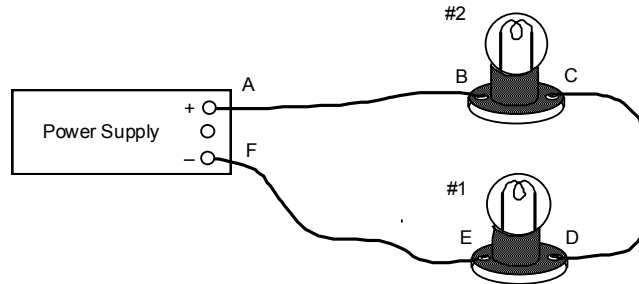


Figure 1: Series Circuit

Prediction

Predict which bulb will be brighter when the two lamps, one a 425 the other a 502, are connected in series and powered by a 5V supply voltage. Give a reason for your prediction based on your results in the previous section.

In which bulb do you predict the current to be greatest, or do you expect the current to be the same in each? Explain.

Procedure

- Now try the experiment. Construct the circuit shown in *Figure 1*. Again, set the power supply at 5 volts. Remember to put a 425 bulb in one socket and a 502 in the other.
- Describe what you observe and discuss any discrepancies with your predictions.

Analysis

There is a mystery here; one bulb is not emitting any light.

One possibility is that there is no current in it. To test this hypothesis, unscrew the bulb that doesn't light. Describe what you observe and why this is evidence that the unlit bulb really did have current in it.

Make an attempt at writing down a reasonable explanation for why the one bulb does not light when it is in series with the other bulb, but does light when it is the lone bulb in a circuit.

Contemplating your explanation, and if possible, consistent with your explanation, make definitive statements/predictions about the resistance of, the voltage across, and the current in each bulb, for this series circuit.

- i. Which bulb do you think has the higher resistance under these operating conditions (425 or 502)? Or do they have the same resistance?
- ii. Through which bulb is the current higher under these operating conditions (425 or 502)? Or is current the same in each?
- iii. Which bulb do you think has the higher voltage dropped across it under these operating conditions (425 or 502)? Or is the voltage across each the same?

Keep your explanation in mind as you explore this circuit more fully in the next section.

c. The equivalent resistance of a series combination

Introduction

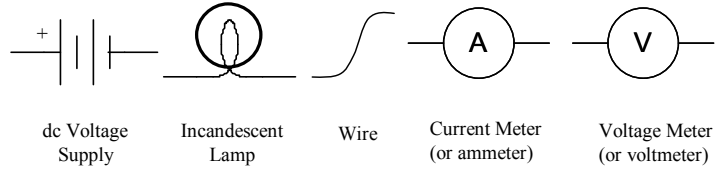
Each bulb's filament acts as an obstacle to the flow of charge and develops a potential drop across it. You can also consider the two bulbs in series as a single obstacle. There is a current in "it" and a potential difference across "it," so "it" has a resistance. In this section you will explore how the resistance of this series combination compares with the resistances of each bulb, and hopefully shed light on the mystery encountered above.

Procedure

- With the two bulbs in series, determine the resistance of each bulb. Remember, since the resistance of a bulb depends on the current in it, you cannot use the ohmmeter setting of the DMM, or the measurements you made in the previous

section, to find the resistances. Rather, you must make new measurements under these different operating conditions.

- In the box below draw three separate circuit diagrams for the three different measurements you must make to determine each bulb's resistance while connected in series and powered by the supply set at 5V. Use only the following symbols as needed.



- Conduct the measurements, making sure to properly configure the DMM for each type of measurement. Use the 10Amp range for the current measurement. Record the results in *Table 2* below, and then calculate the resistance of each bulb under these operating conditions.

Bulb	Measured Bulb Current	Measured Bulb Voltage	Calculated Bulb Resistance (show work)
#502			
#425			

Table 2

Conclusion

Pause here, since you now have the evidence, to check your earlier predictions.

- i. Which bulb has the higher resistance under these operating conditions (425 or 502)? Or do they have the same resistance? Were you correct? (yes or no)
- ii. Through which bulb is the current higher under these operating conditions (425 or 502)? Or is current the same in each? Were you correct? (yes or no)
- iii. Which bulb has the higher voltage dropped across it under these operating conditions (425 or 502)? Or is the voltage across each the same? Were you correct? (yes or no)

Procedure cont.

- What current and what voltage do you need to measure to experimentally determine the combined resistance of the two bulbs in series? In the box below describe the two measurements that need to be made and draw a circuit diagram for each.

- Carry out the measurements, record the results in *Table 3* below, and calculate from your data the combined equivalent resistance of the two bulbs in series.

Measured Current	Measured Voltage	Calculated Combined Resistance (show work)

Table 3

Conclusion

Compare the resistance of the series combination to the resistance of any one of the two bulbs; namely, is it smaller, equal to, or larger than either single bulb resistance?

Do your results suggest a mathematical relationship between the individual resistances and the combined resistance? If so, what?

2. Parallel connections

Introduction

In this part of the lab you will explore *parallel* combinations of bulbs. The behavior of a parallel combination is different than a series combination. It is important that you develop a good understanding of both.

In Part a you will explore a parallel combination of identical bulbs. In part b you will look at a parallel combination of bulbs that are not identical.

a. Parallel circuit with identical elements in each branch

Prediction

Imagine the two circuits shown in *Figure 2*. All three bulbs are the same type. Bulb C in the circuit on the right is said to be “in parallel” with the bulb B, and you say that each bulb sits in a different *branch* of the circuit.

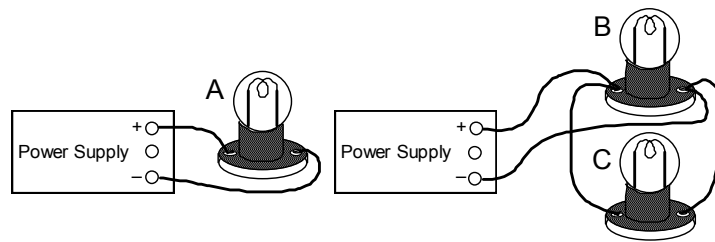


Figure 2: Single Bulb and Parallel Bulb Circuits

Now, make a prediction. What will be the order of brightness of the three bulbs, A, B, and C? In other words, which will be brightest, second brightest, and least bright. You may also say that you think two or more bulbs will have the same brightness. Write down your prediction and a supporting reason.

Procedure

- Build the circuits, using #502 bulbs, and see. A good way to compare brightness, almost simultaneously, is to build only the circuit on the right and watch the brightness of B as you quickly connect and disconnect C. When C is disconnected bulb B behaves as bulb A would. Record the order of brightness. Any surprises?

Conclusion

What can you conclude about the current in each of the parallel bulbs in comparison with the current in the single bulb? (Be careful with this question. Let your observations tell you the answer, not your preconceptions.)

Prediction

Now that you have observed the circuit in operation, check your thinking about current in the circuit. The circuit in *Figure 3* below is exactly the same parallel combination, but the wires have been redrawn in a slightly different way. Let's say the current in wire segments B-G and H-E is i_1 . These are the wires in the branch containing bulb #1, so this is also the current through bulb #1. Relative to i_1 , predict the currents in the other four wire segments. Put your answers in the boxes. (For example, if you think the current is 10 times greater, pencil in $10i_1$.)

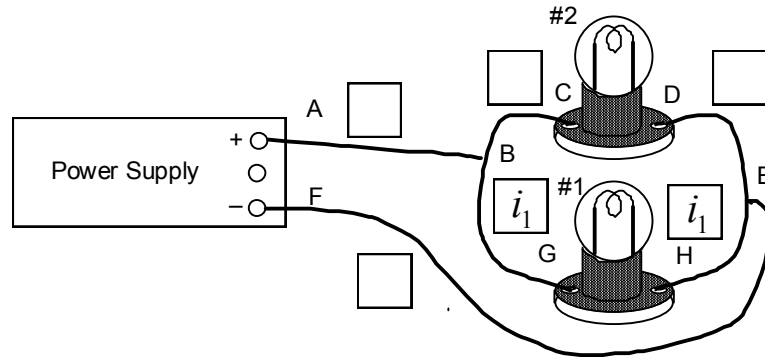


Figure 3: Parallel Bulbs - Prediction

Procedure

- To test your prediction *rewire* the circuit exactly as shown in *Figure 3*. You'll have to use six wires. Note how three connect together at point B and another three at point E. Use the "y" shaped junctions to create these "meeting points". Make sure both bulbs light, equally bright, as a check of your wiring.
- Measure the actual currents in the various branches of the circuit, and write down the results, with units, in the boxes shown in *Figure 4* below. (Note that you will have to think carefully about making this measurement. To measure the current in wire AB you have to replace the wire with the ammeter. The same is true for the wire BC and the others. Use the 10Amp range on the DMM for each of the six measurements.)

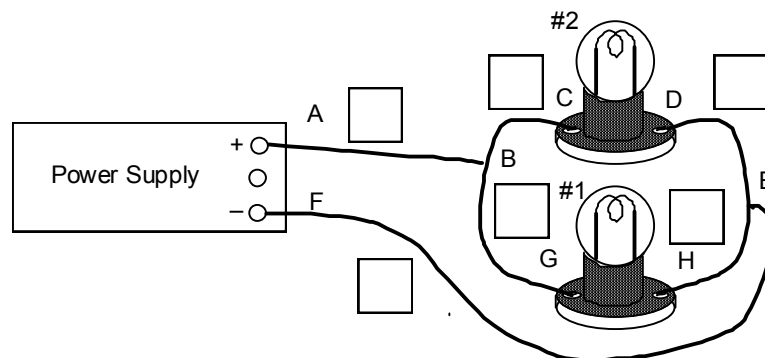


Figure 4: Parallel Bulbs - Measured

- In addition to these current measurement, measure the potential drop across the output terminals of the power supply, the potential difference across bulb #1 and the potential difference across bulb #2. How do they compare?

Check your thinking In a circuit similar to the one above, the current through two identical bulbs in parallel is 3 A. The current delivered by the supply is 6 A. In other words, they split the total, half-and-half. If a *third* identical bulb is connected in parallel with the other two, creating a third branch, what will the current be through each bulb? Give a numerical answer.

For the same circuit, say the supply voltage is 6 V. What resistance do the three parallel bulbs combined present to the power supply? (This is the equivalent resistance of the combination, which can be calculated here as the supply voltage divided by the current delivered by the supply.)

b. Parallel circuit with different elements in each branch

Introduction In the parallel circuit you just studied each branch of the circuit contained an identical #502 bulb. Both bulbs were equally bright, had the same current, and the sum of their currents equaled the total supply current. In this section you will explore what happens when one of the branches is changed in some way so that it is different than the other branch. How does the change in one branch affect the other branch?

Prediction Consider the previous circuit shown in *Figure 3*; both bulbs are type 502. Predict what would happen to the current through bulb #1 if you were to remove bulb #2 from the circuit. Explain.

Procedure

- Try it. Disconnect bulb #2 from the circuit. What do you see? Does what you see agree with your prediction?

- With bulb #2 still disconnected measure the current through bulb #1. Record your result here.

Prediction Predict what would happen to the current through bulb #1 (a type 502) if you were to wire a *different* type of bulb, a 425 bulb, in parallel with the 502. Explain.

Procedure

- While measuring the current through bulb #1 connect the 425 bulb (on the orange base) in parallel with the 502.
- Measure the current through bulb #2, now a 425, and record the result.
- Also measure the current drawn from the positive terminal of the power supply. Record your result.

Analysis

Are the currents in the two branches, one containing a 502 bulb the other a 425 bulb, equal? Is their sum equal to the current from the supply?

Conclusion

Summarize what you have learned about parallel circuits with two branches by answering these three questions.

- i) Describe how the currents in the branches of a parallel circuit compare to the total current.
- ii) Describe how the current in one branch depends on the current in the other branch.
- iii) Describe how the voltages across the two branches compare with each other and with the voltage produced by the power supply.

c. The equivalent resistance of a parallel combination

Introduction

Each bulb acts as an obstacle to the flow of charge and develops a potential drop across it. You can also consider the two bulbs in parallel as a single obstacle. There is a current through “it” and a potential drop across “it,” so “it” has a resistance. In this section you will explore how the resistance of this parallel combination compares with the resistances of each bulb.

Procedure

- Determine the resistance of the 502 and 425 bulbs while operating in parallel. You have made all the necessary current and voltage measurements previously. Compile your results in *Table 4* below. Then calculate the resistance of each bulb. If you are unsure about any measurement, repeat it.

Bulb	Measured Bulb Current	Measured Bulb Voltage	Calculated Bulb Resistance (show work)
#502			
#425			

Table 4

- What current and what voltage do you need to measure to experimentally determine the combined resistance of the two bulbs in parallel? Describe the two measurements that need to be made. Draw a circuit diagram if you think that would help your explanation. If you have made them previously record your results immediately in *Table 5* below; if not, make the measurements first and then calculate the combined resistance.

Measured Current	Measured Voltage	Calculated Combined Resistance (show work)

Table 5

Conclusion

Compare the resistance of the parallel combination to the resistance of each bulb individually; namely, is it smaller, equal to, or larger than either single bulb resistance?

How does the measured equivalent resistance compare to the result obtained from the formula for combining parallel resistances, $R_{eq} = (1/R_1 + 1/R_2)^{-1}$? Show your work.

3. Series-parallel circuits

Introduction

In the last part of this lab you will examine circuits that contain a combination of series and parallel components.

a. First look at a series-parallel circuit

Introduction

The questions that follow deal with the circuit shown in *Figure 5*. Assume that it is built with three identical bulbs.

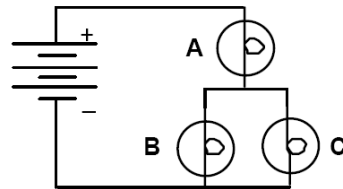


Figure 5: A series-parallel combination

Questions

1. Predict the order of brightness of the three bulbs. Explain your reasoning. Then, build the circuit to test your prediction, and comment.
2. In this circuit bulbs **B** and **C** are in parallel. If you unscrew **C** from its socket will the brightness of bulb **B** change? If yes, will it be brighter or dimmer? Explain. Then build the circuit to test your prediction, and comment.
3. In the previous section, when you worked with bulbs in parallel, unscrewing one bulb produced no change in the brightness of the second. Why is this no longer the case? Explain.

- For the circuit in *Figure 5*, rank the potential drops across each bulb. Explain. Then measure the potential drops with the multimeter to test your ranking and record the results.

$$(V_A = \underline{\hspace{2cm}} \quad V_B = \underline{\hspace{2cm}} \quad V_C = \underline{\hspace{2cm}})$$

- Predict what will happen to the voltage across bulb **B** if you unscrew bulb **C**. Explain. Then test your prediction and comment.

b. Short circuits

Introduction

A “short circuit” is a frequent problem in electrical circuits. A short circuit is simply a wire, or other good conductor, connected across a circuit element, like a bulb. Thus, you can think of a short circuit as a resistor with $R = 0$.

Questions

- Still working with the circuit shown in *Figure 5* predict what will happen to the brightness of *all three* bulbs if you short out bulb **C** by clipping a wire across its leads. Then try it, and measure the potential drop across each bulb. Describe what you observe and any discrepancies with the predictions you made.
- Predict what will happen to the brightness of *all three* bulbs if a short was created across bulb **A** instead of **C**. Then try it and comment on the result.

c. Open circuits

Introduction

An “open circuit” is a break in a circuit through which no charge can pass. In the series-parallel circuit you created an open circuit when you unscrewed bulb **C** in question 2 of section **a** above. Another common open circuit is a switch in the “off” position. You might think of an open circuit as a resistor with $R = \infty$.

Question

1. Imagine creating an open circuit, in the circuit shown in *Figure 5*, by unscrewing bulb **A** from its socket. Predict the voltage across the now empty socket that held bulb **A**. Then try it, unscrew bulb **A** and use the multimeter to measure the voltage across the empty socket. Comment on the result.

d. More multi-bulb circuits

Introduction

Consider the series-parallel circuit in *Figure 6* containing three identical bulbs. Make a prediction of the relative brightness of the bulbs. (You do not have to write out your prediction.) Check your reasoning against the reason given below.

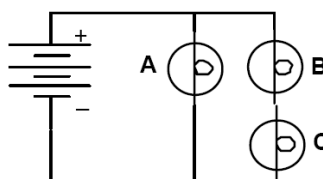


Figure 6: 3-bulb circuit

Answer: Here is how you might reason your way to a sound prediction. Bulbs **B** and **C** are in series, and together the unit, (**B+C**) is in parallel with **A**. Because they are in parallel the potential drop across bulb **A** is the same as that across (**B+C**). Current is potential drop divided by resistance. Since (**B+C**) is a series combination, its resistance is larger than **A**. So the current through the unit (**B+C**) is less than that through **A**. Because bulbs **B** and **C** are in series, each has the same current, and thus will be equally bright. So, bulb **A** must have the largest current and be the brightest. **B** and **C** have equal but smaller currents, so they are equal in brightness and dimmer than **A**. Thus

$$\mathbf{A} > \mathbf{B} = \mathbf{C}$$

Questions

1. Make predictions, using the same type of reasoning, for the four-bulb circuits shown in *Figure 7* below. You don't have to write down your explanations, just your rankings. Then build each circuit to test your predictions, and comment.

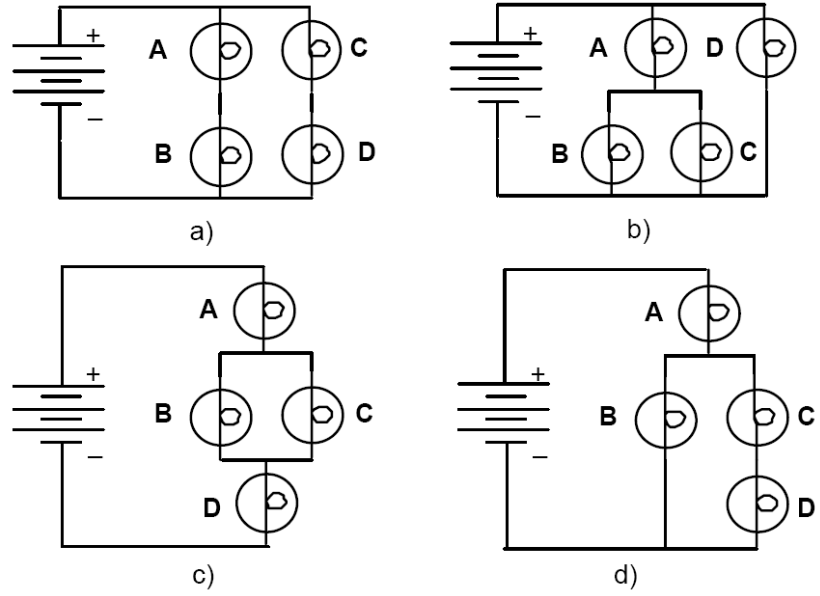


Figure 7: Four-bulb circuits